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A STUDY OF FINEBLANKING FOR THE MANUFACTURE OF FLUERIC LAMINAR --ETC(U)

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A nonconventional stamping process, known as fineblanking, is investigated for use in high-volume production of flueric laminar proportional amplifiers. The investigation includes the standard deviation of critical dimensions, supply and control flow measurements for a constant pressure, amplifier gain, common-mode rejection ratio (CMRR), and cost breakdown. The present study indicates that fineblanking yields a significant OVER

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improvement over metal photochemical etching (a widely used fabrication technique) in the repeatability of geometric parameters. Typical standard deviations of a nozzle width are less than 0.5 percent. Further, a 61.3-percent improvement of the mean CMRR was observed.

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1. INTRODUCTION

Currently, the most widely used process for fabrication of fluidic elements in military applications is metal photochemical etching. This process offers good reproducibility of complex geometries, satisfactory accuracy, good packaging capability, and relatively low cost. Satisfactory accuracy (tolerance of 0.0127 mm or 0.0005 in.), however, can only be achieved by using thin foils of 0.05- to 0.127-mm (0.002- to 0.005-in.) thickness, and thus requires stacking of laminates. Ideally, the number of laminates necessary to form a single component should be small, to minimize the problem of proper sealing.

Fineblanking, a relatively new fabrication technique, is essentially a stamping process with zero clearance between male and female dies. This technique offers many of the advantages of metal etching along with several advantages of its own. The ability of fineblanking to consistently maintain better dimensional tolerances is by far this technique's greatest asset. In addition, thicker sheet stock may be used (0.25 mm or 0.01 in.) greatly alleviating the sealing problems associated with stacked laminates. Although fineblanking has several distinct advantages, the process is not without flaw. The presence of a machining or extrusion burr has been shown to have a direct effect on performance of laminar proportional amplifiers (LPA's). The size of this burr is primarily dependent on the material used. Brass and aluminum yield the worst burr, typically extending about 0.025 mm (0.001 in.) from the surface. However, an approximately 80-percent reduction in burr size can be effected by using stainless steel. It must also be noted that, because of the relatively high initial cost of the die set, this process is economically desirable only where high-volume production of a particular design is required.

This work is intended to evaluate the fineblanking fabrication technique for LPA's by a dimensional and performance comparison with the metal photochemical etching process. Random samples of both methods were selected and the following characteristics were compared.

(a) Standard deviation of critical dimensions

(b) Standard deviation of amplifier gain at 10-percent control bias pressure

(c) Standard deviation of supply and control flow for a given constant pressure

(d) Common-mode rejection ratio

(e) Comparative cost breakdown

2. THE FINEBLANKING PROCESS

Conventional blanking or stamping work produces parts with sheared surfaces which are only partially--generally one third--cleanly sheared, the remaining two thirds showing a rough break.[1] In fineblanking, the metal is cleanly sheared over its entire thickness in one single operation. Since the metal thickness is completely sheared, a much better internal surface finish is obtained. It is for this reason that dimensional tolerances are much better than those associated with conventional stamping or blanking. These two qualities cannot be overemphasized when dealing with small fluidic elements since surface finish and geometric variations greatly affect the performance of such elements.

A simplified schematic of the fineblanking process is presented in figure 1. The pressure plate has firmly clamped the material to the die plate in figure 1(a) and the ejector begins applying a counterpressure to the upcoming punch. During the actual shearing, the die plate and pressure plate are stationary and maintain constant pressure on the material. The ejector also continues to maintain a constant

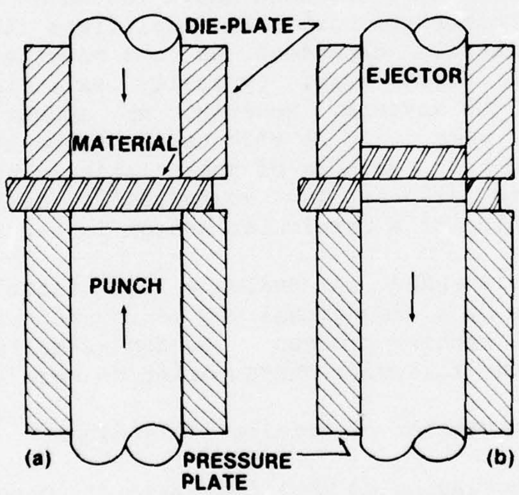

Figure 1. Simplified fineblanking process:
(a) before pressure is applied,
(b) after shearing.

[1] *Fine-Blanking Practical Handbook, Ch 1, Feintool AG, Lyss, Switzerland, (1972).*

counterpressure, pressing the material firmly against the face of the punch. In figure 1(b), the piece part is sheared into the die plate. The pressure clamping the material and the ejector pressure are then relieved. The tool is opened, the ejector forces the piece part out of the die plate, and the process continues.

Fineblanking distinguishes itself from conventional stamping in three ways:

(a) the punch never enters the die (no tolerance between punch and die),

(b) a constant counterpressure is always maintained on the piece part by the ejector, and

(c) the die plate has a very small radius.

One drawback to this process is the presence of a burr. Figure 2 depicts the burr and die roll that accompany fineblanking.

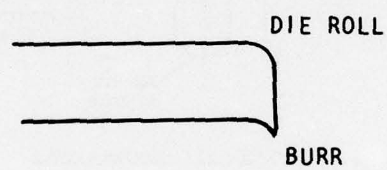

Figure 2. Die roll and burr.

This burr has a tendency to make sealing more difficult, particularly if the laminates are stacked. The orientation of stacked laminates relative to each other (for example, facing each other) also has an effect on performance. The effect of these burrs on performance was observed and is presented later in this report.

3. EXPERIMENTAL RESULTS

3.1 Geometric Comparison

The first stage of the evaluation of fineblanking was a statistical comparison of critical dimensions for both fineblanked and metal-etched LPA's. These dimensions are labeled on the amplifier schematic in figure 3 and the key is given in table I.

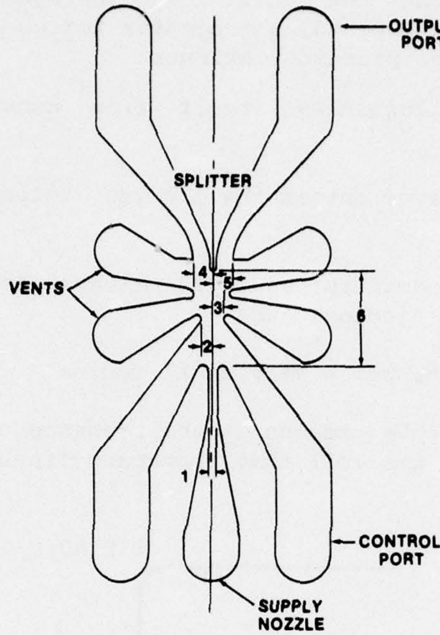

Figure 3. Critical dimensions inspected (HDL Model 2-2B LPA).

TABLE I. STANDARD DEVIATION OF CRITICAL DIMENSIONS

Dimensions (key to labels in fig. 3)	Standard Deviation / Mean (%) Fineblanked (brass)	Standard Deviation / Mean (%) Metal etched	Nominal dimensions (mm)
1. Supply-nozzle width	0.38	2.21	0.05
2. Left control edge (distance from center line)	0.49	2.42	0.5
3. Right control edge (distance from center line)	0.42	3.0	0.5
4. Left-receiver width	0.45	0.66	0.76
5. Right-receiver width	0.36	0.84	0.76
6. Nozzle-to-splitter distance	0.22	0.34	4.1

Fineblanking, a prototype fabrication technique for LPA's, can only be as accurate as the accuracy of the punch and die. Since the fineblanked amplifiers tested were a "first run," the chance of under- or oversized elements was good. It must be noted, however, that even if under- or oversized, all elements should be identical. Therefore, the standard deviation of the dimensions was adopted as a means of comparing the processes. Before an actual production run, the punch and die would, of course, be properly inspected to insure correct final dimensions. Table I shows the results for 10 random samples of each fabrication technique.

For every dimension examined, fineblanking had a better repeatability than metal etching, and in most cases a significant improvement can be seen.

3.2 Comparison of Amplifier Performance

3.2.1 Gain

The tests of the LPA gain performance were designed so as to yield quantitative gain data as well as data on the effect of the burr and die roll. Identical tests were performed on brass fineblanked amplifiers composed of two 0.254-mm laminates; the only modification was that the laminates were flipped to change their relative position and produce the desired data on the burr and die roll. It was found that for the worst case--burrs facing each other--the standard deviation of the gain was 6.4 percent. For the optimum orientation--burrs facing away from each other--the standard deviation of the gain was 4.9 percent. At a control bias pressure, P_C, of 10 percent of the supply pressure, P_s, stainless-steel amplifiers exhibited only a 3.3-percent standard deviation in gain, comparable to the 3.7-percent standard deviation in gain for metal-etched amplifiers. This reduced deviation was apparently due to the reduction in burr size associated with the less ductile stainless steel. Stainless-steel fineblanked amplifiers also showed a 13-percent improvement in mean gain over metal-etched amplifiers, although this improvement was due in part to the slightly different aspect ratio. (The experimental test setup and corresponding conditions appear in app A.)

3.2.2 Standard Deviation of Supply and Control Flow for a Constant Pressure

In the following set of tests, which were performed to establish the repeatability of the supply and control channels, the experimental precision was first determined by performing 10 identical tests on the same single-laminate amplifier. The base standard

deviation of the flow divided by the mean flow was then computed. Table II presents these data and the tabulated standard deviations for 10 random samples of single-laminate amplifiers fabricated by both fineblanking and metal etching.

In all cases, fineblanked amplifiers showed better repeatability than the metal-etched amplifier samples. This is an expected result since the dimensional deviation of fineblanked amplifiers is less than that of the metal-etched amplifiers. Fineblanking also yields a better internal surface finish.

TABLE II. STANDARD DEVIATION OF SUPPLY AND CONTROL FLOWS FOR CONSTANT PRESSURE

Test A. Supply flow (Q_s) at constant supply pressure (P_s)

Fabrication technique	P_s (kPa)	Q_s ($\times 10^{-6}$ m^3/s)	$\frac{\text{Standard deviation}}{\text{Mean}}$ (%)
Fineblanked (brass)	2.4	5.172	1.2
Metal etched	4.12	4.748	1.5

Note: Experimental precision was 0.5%.

Test B. Control flow (Q_c) at constant supply pressure and control pressure (P_c)

Fabrication technique	P_s (kPa)	P_c	$\bar{Q}_c$ ($\times 10^{-6}$ m^3/s)	$\frac{\text{Standard deviation}}{\text{Mean}}$ (%)
Fineblanked (brass)	2.5	10% P_s	1.616	1.4
Metal etched	4.12	10% P_s	1.253	2.1

Note: Experimental precision was 0.9%.

Test C. Control flow at constant control pressure, no supply flow

Fabrication technique	P_s	P_c (kPa)	$\bar{Q}_c$ ($\times 10^{-6}$ m^3/s)	$\frac{\text{Standard deviation}}{\text{Mean}}$ (%)
Fineblanked (brass)	0	0.25	3.257	0.7
Metal etched	0	0.412	2.391	2.3

Note: Experimental precision was 0.7%.

3.2.3 Common-Mode Rejection Ratio

Common-mode rejection ratio (CMRR), the measure of symmetry of a device, was measured at P_c equal to 10-percent P_s for metal-etched laminates and for stainless-steel fineblanked laminates. The mean CMRR and its standard deviation provide information as to the degree of overall geometrical asymmetry and the consistency of such asymmetries between amplifiers. The CMRR is defined as the ratio of the change in output pressure for a change in differential-control pressure to the change in output pressure for a change in common-mode pressure, or

$$\text{CMRR} = \frac{G_{\text{amplifier}}}{\begin{array}{c}\text{common-mode}\\ \text{transfer}\\ \text{ratio}\end{array}} = \frac{\left.\dfrac{\delta\left(\Delta P_{out}\right)}{\delta\left(\Delta P_{in}\right)_D}\right|_{\text{amplifier}}}{\left.\dfrac{\delta\left(\Delta P_{out}\right)}{\delta\left(\Delta P_{in}\right)_C}\right|_{\text{common mode}}} ,$$

where

G = gain,

δ = change,

ΔP = differential pressure,

ΔP_{out} = difference between the pressure at the left and right outlets,

ΔP_{in} = difference between the pressure at the left and right inputs,

$\delta\left(\Delta P_{in}\right)_D$ = change in the differential control pressure, and

$\delta\left(\Delta P_{in}\right)_C$ = change in pressure at the controls with the pressure at both controls being kept equal.

Thus, if the output pressure does not change for a common-mode signal, the device is completely symmetrical and the ratio is infinite. Table III gives the experimentally determined mean and standard deviations of the CMRR.

Appendix A presents a detailed explanation of the experimental method used to determine the CMRR.

TABLE III. MEAN COMMON-MODE REJECTION RATIO (CMRR) AND STANDARD DEVIATION OF CMRR

Fabrication technique	Mean CMRR	Standard deviation (%)
Stainless-steel fineblanked	257.5	55.3
Metal etched	157.8	56.8

As expected, because of better dimensional repeatability, the stainless-steel fineblanked amplifiers produced a higher CMRR than did the metal-etched amplifiers. Because of the nature of experimental derivatives, the standard deviation of the CMRR could not be distinguished from the standard deviation of the CMRR of metal-etched amplifiers.

4. MANUFACTURING COST OF FINEBLANKING VERSUS METAL ETCHING

The cost of manufacture by both fineblanking and metal etching is determined primarily by the required number of parts of a particular design. Fineblanking is economical for high-volume (more than 100,000 pieces) production only. Metal etching, on the other hand, has proven to be the most cost-effective technique for quantities of several hundred to tens of thousands.

For fineblanking any given amplifier design, an initial outlay of about $10,000 is required for the punch and die. Metal etching requires only a $400 to $600 initial outlay for the amplifier pattern and associated artwork. Excluding the initial outlay, the cost of manufacture then becomes a function of the number of parts. For large quantities, fineblanking can produce stainless-steel laminates 0.25 mm (0.01 in.) thick at a cost of $0.19 per laminate. Material cost is approximately $0.01 per laminate, and an average punch and die resharpening cost of $0.01 per laminate would also be required, thus bringing the total cost to $0.21 per laminate. Metal etching can produce stainless-steel laminates 0.1 mm (0.004 in.) thick at a cost of $0.22 per laminate, material included. Now, amortizing the die cost over, say, 100,000 pieces and adding this to the manufacturing cost, the total cost is $0.32 per laminate. For any parts made after 100,000, the punch and die are paid for, and hence the cost per laminate drops to $0.22. Since fineblanked laminates can be 2.5 times the thickness of metal-etched laminates, the metal-etching cost must be multiplied by 2.5, bringing the total cost to $0.55 per unit fineblanked thickness.

Tool life for the punch and die is difficult to estimate. Resharpening, a half man-day effort, is probably necessary every 20,000 to 30,000 pieces. It can be estimated, however, that the capability of the punch and die is well over a million pieces since only a very small amount (~0.02 mm) must be removed when resharpening, and the punch and die are over 25 mm thick.

Further, relatively little quality control is necessary for fineblanked laminates. If the last laminate in a batch of several hundred is in tolerance, it is safe to assume that all the preceding laminates are dimensionally in tolerance. Metal etching, however, requires that each laminate be inspected individually to insure correct dimensional tolerance.

5. SUMMARY AND CONCLUSIONS

Overall, fineblanking is seen to offer some real advantages over metal photochemical etching for high-volume fabrication of flueric LPA's. The standard deviation of the critical dimensions inspected was 0.39 percent, average, for fineblanking compared with an average of 1.58 percent for metal etching. Fineblanked amplifiers also showed improved performance, although not as markedly, probably because of the burr. It was found that the use of stainless steel as opposed to brass can reduce the standard deviation of the gain from 4.9 to 3.3 percent because of the smaller burr associated with stainless steel. With P_c equal to 10-percent P_s, stainless-steel fineblanked elements showed a slight (11-percent) improvement in the variation of gain over metal-etched elements, and a 13-percent improvement in mean gain. Flow measurements for the supply jet and controls for a constant pressure (tests A, B, and C) consistently produced lower standard deviations for the fineblanked elements than for those that were metal etched. The mean CMRR for metal-etched amplifiers (157.8) was significantly lower than that for fineblanked amplifiers (257.5). Before any volume production could begin, the punch and die would have to be properly sized and made symmetrical. Not only could fineblanking give a higher CMRR, but it could also yield lower standard deviations.

The fact that fineblanking is economical only for high-volume production is considered a drawback. However, if high-volume production is required, fineblanking appears to be the most desirable fabrication technique currently available.

APPENDIX A.--EXPERIMENTAL SETUP AND CORRESPONDING TEST CONDITIONS

A-1. INTRODUCTION

In order to compare the performance of fineblanked and metal photochemically etched laminar proportional amplifiers (LPA's), tests were run on the gain, supply, and control flow for a constant pressure, and on the common-mode rejection ratio (CMRR). A statistical analysis of the results was then performed as a means of comparison.

A-2. GAIN

The gain was determined by applying a push-pull signal at the inputs of the LPA and monitoring the output pressure. The differential output pressure was then recorded as a function of differential input pressure, the slope of the curve being the gain.

Test conditions:

(1) All amplifiers in this test and subsequent tests were Harry Diamond Laboratories (HDL) model 2-2B.

(2) The fluidic signal generator (fig. A-1) consisted of a flapper valve driven by a torque motor. The torque motor in turn was driven by an electronic signal generator.

(3) The resistance load (blocked output) was infinite.

(4) The aspect ratio of the fineblanked LPA's was 1.0; for the metal-etched LPA's, it was 0.8.

(5) The modified Reynolds number used was 50 (see sect. A-5).

(6) The constant dc control bias pressure, P_c, was 10 percent of the supply pressure, P_s.

(7) The computations were based on 10 random samples of each method. The test setup is shown schematically in figure A-1.

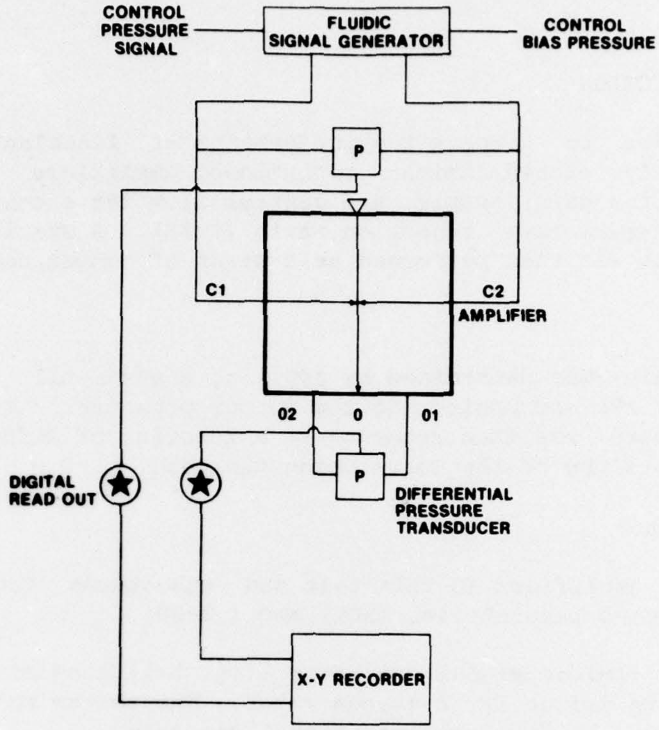

Figure A-1. Method for determining gain.

A-3. STANDARD DEVIATION OF SUPPLY AND CONTROL FLOW FOR A CONSTANT PRESSURE

The standard deviation of supply and control flow for a constant pressure was determined by applying and maintaining a constant pressure and then measuring the resulting flow. The standard deviation for 10 samples of each fabrication technique was then computed.

Test conditions:

(1) All flows were monitored with a calibrated laminar flowmeter.

(2) All pressures, including flowmeter differentials, were monitored with electronic pressure transducers with digital display.

(3) The test items were HDL 2-2B LPA's.

(4) All tests were run at an identical modified Reynolds number of 50 (see sect. A-5).

(5) The aspect ratio of the fineblanked LPA's was 0.5 (single laminate); for the metal-etched LPA's, the ratio was 0.375 (single bonded unit).

(6) Control pressures (tests B and C) were set at 10-percent P_s. Both controls were tested simultaneously.

A-4. COMMON-MODE REJECTION RATIO

First, the amplifier gain at 10-percent P_s control bias pressure was measured as shown in figure A-1. The common-mode transfer ratio, defined here as the change in output-pressure differential per unit common-mode input signal, was then measured (fig. A-2) and the CMMR formed. A pressure of 10-percent P_s was applied common mode and electronically offset to zero. As the gain and common-mode transfer ratio curves crossed the zero differential output line, the control pressure in each test was equal at a value of 10-percent P_s. The gain and common-mode transfer ratio were then measured at this crossing.

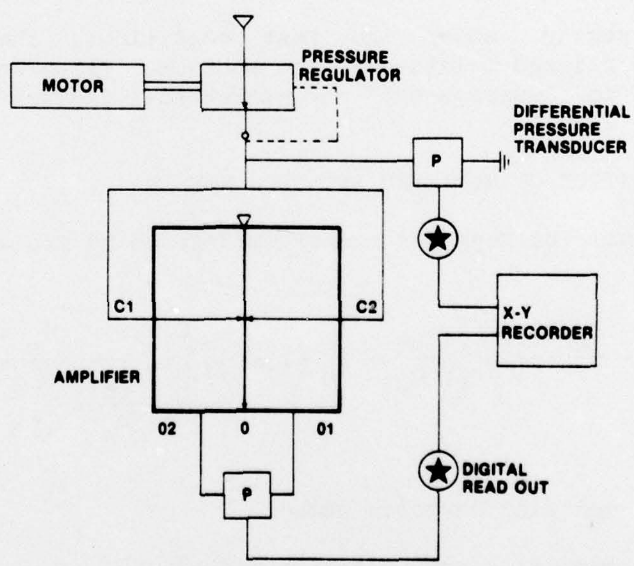

Figure A-2. Method for determining common-mode transfer ratio.

Test conditions:

(1) For gain measurement, conditions were identical to those described in section A-2.

(2) Stainless-steel fineblanked amplifiers were composed of four 0.127-mm thick laminates yielding an aspect ratio of 1.0. Metal-etched amplifiers were composed of four 0.1-mm thick laminates yielding an aspect ratio of 0.8. In both cases, the laminates were alternately flipped.

(3) All amplifiers were tested at a modified Reynolds number of 50. The corresponding supply pressures were

stainless-steel fineblanked	3.84-mm Hg,
metal etched	6.16-mm Hg.

(4) The common-mode transfer ratio was determined by the arrangement shown in figure A-2. A motor-driven pressure regulator was used to generate the common-mode signal.

(5) The standard deviation and mean were based on 10 samples of each.

As stated under the test conditions, the laminates were alternately flipped relative to one another. Flipping the laminates has a tendency to "average out" any geometrical asymmetries, thus yielding the highest CMRR.

A-5. DEFINITION OF MODIFIED REYNOLDS NUMBER

The modified Reynolds number is defined by Drzewiecki[1] as:

$$N_{Ra} = \frac{b_s}{\nu}\left(\frac{2P_s}{\rho}\right)^{1/2} \Bigg/ \left[\left(\frac{\ell_{th}}{b_s} + 1\right)\left(1 + \frac{1}{\sigma}\right)^2\right] = \frac{N_R}{\left(\frac{\ell_{th}}{b_s} + 1\right)\left(1 + \frac{1}{\sigma}\right)^2}$$

where

N_{Ra} = modified Reynolds number,

b_s = amplifier supply-nozzle width,

---

[1] *Tadeusz M. Drzewiecki, A Fluid Amplifier Reynolds Number, II, Proceedings of the 1974 Fluidic State-of-the-Art Symposium (October 1974).*

ν = fluid kinematic viscosity,

P_s = amplifier supply pressure,

ρ = fluid density,

ℓ_{th} = amplifier supply-nozzle throat length,

σ = amplifier supply-nozzle aspect ratio, and

N_R = Reynolds number.

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